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No.388

United States Department of Agriculture

Forest Service

North Central Research Station

Research Note NC-388
2004

Identification of *Armillaria* Species in the Chequamegon-Nicolet National Forest

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ABSTRACT.—*Armillaria* species were isolated from coniferous and deciduous overstory species in 17 of 22 stands in the Chequamegon area of the Chequamegon-Nicolet National Forest. *Armillaria calvescens* and *A. sinapina* were identified once each, and the remainder of the isolates were *A. ostoyae*. These findings are related to reports of *Armillaria* species from other areas of North America, particularly the western Great Lakes States, and to the potential role of *Armillaria* root disease in the Chequamegon.

KEY WORDS: *Armillaria*, root disease, Cheqamegon-Nicolet.

The Chequamegon area of the Chequamegon-Nicolet National Forest in northwestern Wisconsin covers 348,000 hectares, nearly 90 percent of which are classified as timberland (Haugen *et al.* 1998). In addition to wood and wood products, the lands are managed for wildlife habitat and numerous forms of recreation. Beginning in the late 1980s, USDA Forest Service personnel observed tree mortality and decline in some areas of the Chequamegon. *Armillaria* root disease, important in several areas of North America (Bruhn *et al.* 2000, Lundquist 2000, Mallett and Maynard 1998, McLaughlin 2001b, Morrison *et al.* 2001, Rizzo and Slaughter 2001), was suspected of contributing to these observed declines, but no mycological investigations had been done in this area.

The objectives of this study were to identify the species of *Armillaria* present in the Chequamegon, especially in declining stands, and to relate these findings to previously collected information about *Armillaria*, particularly in the western Great Lakes States, but also in other areas of North America. This is the first step in assessing the role of these fungi in the Chequamegon forest.

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MATERIALS AND METHODS

Stands with dead and dying trees were selected first because the presence of *Armillaria* species was strongly suspected, and other stands were selected to represent the major overstory species of the forest. The root collars, butts, and one meter of lateral roots of recently killed or declining trees were examined for signs (mycelial fans or rhizomorphs) of *Armillaria*. The soil was carefully removed from around the base and lateral roots of these trees, and small areas of bark were lifted or peeled back. In stands where dying or declining trees were not observed, stumps and snags were examined. Samples of roots, root collars, and butts harboring *Armillaria*-like mycelial fans, rhizomorphs, or white stringy rot were collected for isolation, and the soil surrounding the sampled substrate was examined for rhizomorphs, which were collected if present. Host species, substrate type, and diameter at 1.3 m or at ground level, for trees and stumps, respectively, along with the location and form (fan, rhizomorph, decayed wood) of *Armillaria* observed were recorded for each sample. Overall condition of the tree, and the presence of decay, other fungi, and insect or disease problems were also noted. One or two samples for isolation were collected per stand. Sampled materials were placed in paper bags and stored in a cooler while traveling (1 to 2 days), then placed in cold storage (4 C°) for 1 to 4 days until isolations were completed.

Isolations were made following procedures described by Rizzo and Harrington (1993). Small (≤ 5 mm) pieces of mycelial fans and/or wood were taken from where the bark was removed and plated both on water agar (WA, 15 g Difco agar per L) and on basidiomycete-select agar (BSMA, 15 g malt extract and 15 g agar per L, amended with 4 ug/ml benomyl 50WP and 100 ug/ml streptomycin sulfate after autoclaving (Harrington *et al.* 1992)). Rhizomorphs were surface disinfected by soaking in an aqueous solution of 20 percent ethanol and 10 percent bleach for 2 minutes, then rinsed in sterile distilled water. These were cut into 1-cm segments and plated. Plates were incubated under laboratory conditions (20-25 C°). To obtain pure cultures, transfers onto 1 percent malt extract agar (MEA) were made 1 to 2 weeks after isolation, and, if necessary, a second transfer was made 4 weeks later.

Diploid-haploid pairings, per Korhonen (1978), were used to identify the unknown *Armillaria* isolates to species. Each unknown presumably diploid isolate was paired with 8-12 haploid testers (table 1), which were obtained from David Rizzo (Rizzo 1993). One 3-mm plug of the tester strain was placed on 1 percent MEA, 5 mm away from a plug of the unknown. Plates were

Table 1.—*Tester isolates used in haploid-diploid pairings for identification of* Armillaria *species*

Species	Isolates
A. ostoyae	A37[1], A100
A. gallica	A74, A102, A103
A. gemina	A80, A78[1]
A. sinapina	A48, A52[1]
A. calvescens	A77[1], A7[1]
A. mellea	A72[1]

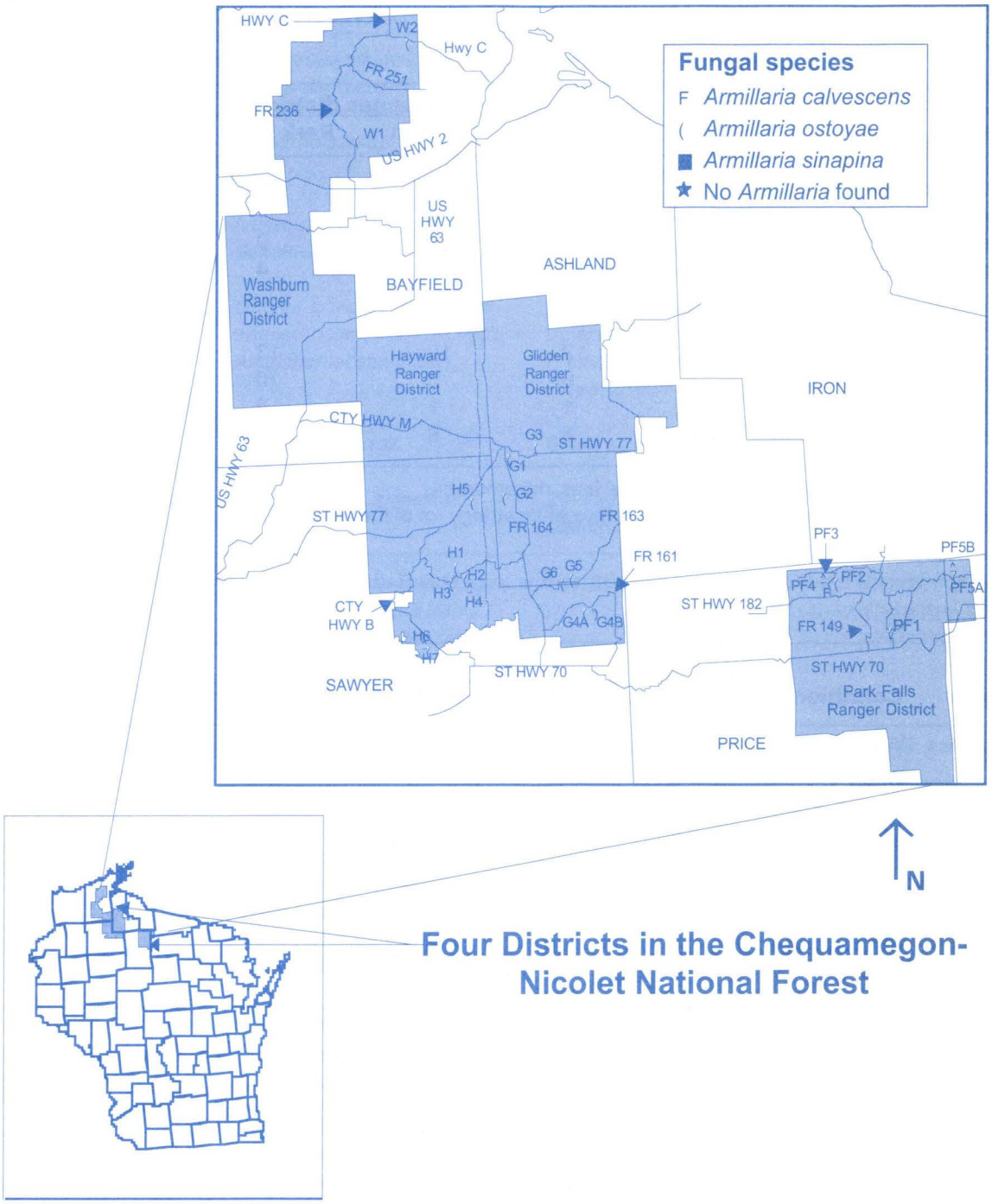
[1]Listed in: Harrington, T.C.; Rizzo, D.M. 1993.

incubated under laboratory conditions for 5-7 weeks, at which time all pairings were subcultured. As described by Harrington *et al.* (1992), three 3-mm plugs were taken from the tester (haploid) side of the pairing—one from the margin of the tester advancing toward the outside of the plate (away from the plug), one from the middle of the tester growth area, and one from between these two—and transferred to new plates of 1 percent MEA. These were incubated for 10-14 days and then visually evaluated. Rizzo and Harrington (1992) demonstrated that nuclear migration occurs from the diploid to the haploid in conspecific pairings and that, in most cases, this method should be considered a reliable means of identifying *Armillaria* to species. Mycelial growth of single-spore haploid isolates (the testers) is usually whitish and fluffy, with much aerial mycelia. Growth of diploid isolates (unknowns) tends to be flat, brown to dark brown, and becomes crustose in many cases. If the growth of the subcultured plug from the middle of the tester colony and at least one other subculture differed in morphology from the original tester strain, i.e., were flat and/or crustose rather than fluffy, the unknown was considered to be the same species as the tester strain.

RESULTS AND DISCUSSION

Twenty-two stands in the four ranger districts of the Chequamegon (Hayward, Glidden, Washburn, and Park Falls) were inspected for *Armillaria* between June and August 1992 (fig. 1). Stands varied in age and some were recently clearcut. While most stands were predominantly conifer overstory, stands of pure and mixed overstory were included. No fruiting bodies of *Armillaria* were observed during this survey, because their production occurs in the fall. However, *Armillaria* fans and/or rhizomorphs were observed in 86 percent of the stands and *Armillaria* species were isolated from material collected in 90 percent (17 of 19) of those stands (table 2, fig. 1). Although the distributions of *Armillaria* species are probably irregular throughout the Chequamegon, the genus is considered to be ubiquitous in forested areas, and a more thorough examination of potential substrates would be required to claim that *Armillaria* species were "absent" from a stand. *Armillaria* fans and/or rhizomorphs were observed on 78 percent of 37 samples collected and *Armillaria* species were isolated from 76 percent (23 of 29) of those samples. Whereas *Armillaria* species were isolated from both live and dead conifers, the fungi were isolated only from dead deciduous trees (table 3).

Of the 23 *Armillaria* isolates identified from the Chequamegon, 21 were *A. ostoyae*, 1 was *A. sinapina*, and 1 was *A. calvescens*. Since the late 1980s, each of these species has been identified in the western Great Lakes region, and root disease associated with *A. ostoyae* has been reported on several conifer and deciduous hosts (table 4). Species of *Armillaria* are not confirmed



Four Districts in the Chequamegon-Nicolet National Forest

Figure 1.—*Stands in the Chequamegon-Nicolet National Forest that were examined for the presence and identification of* Armillaria *species. Each stand is designated by a letter and number (e.g., H5 = Hayward Ranger District, stand number 5).*

Table 2.—*Numbers of stands and samples examined for* Armillaria *species by ranger district in the Chequamegon area of the Chequamegon-Nicolet National Forest*

Stands	Ranger district				Total
	Hayward	Glidden	Park Falls	Washburn	
Total no. examined	7	7	6	2	22
No. with signs[1] of *Armillaria*	5	6	6	2	19
No. with symptoms[2] only	0	1	0	0	1
No. from which *Armillaria* was isolated	5	6	4	2	17
Samples					
Total no. examined	12	10	13	2	37
No. with signs of *Armillaria*	9	8	10	2	29
No. with symptoms only	1	1	2	0	4
No. from which *Armillaria* was isolated	8	8	5	2	23

[1]Only assessed belowground, signs are mycelial fans, rhizomorphs.
[2]Only assessed belowground, the main symptom is white stringy rot of the wood.

Table 3.—*Numbers and condition of trees from which* Armillaria *species were isolated by ranger district in the Chequamegon area of the Chequamegon-Nicolet National Forest*

Tree type	Condition	Ranger district				Total
		Hayward	Glidden	Park Falls	Washburn	
Conifer	Living	1	0	1	0	2
	Dead	3	4	1	1	9
	Stump, snag	4	1	2	0	7
	Total	8	5	4	1	18
Deciduous	Living	0	0	0	0	0
	Dead	0	3	1	1	5
	Stump, snag	0	0	0	0	0
	Total	0	3	1	1	5

for the earliest publications from this region, either because isolations were not made or because the work occurred before several intersterile groups were identified within the original *A. mellea* complex (Anderson and Ullrich 1979, Korhonen 1978, Shaw and Kile 1991, Volk and Burdsall 1995).

The finding of *A. calvescens* on *Acer saccharum* Marsh. is consistent with other reports from the western Great Lakes States, and from New York and Ontario (Banik *et al.* 1995, Blodgett and Worrall 1992, McLaughlin 2001a). Although most often causing a butt rot, *A. calvescens* has been identified as a factor in a decline of sugar maple in New York (Bauce and Allen 1992).

McLaughlin (2001a) reported *A. saccharum* as a host of *A. sinapina* in Ontario, but the identification from the Chequamegon may be the first report of *A. sinapina* on this host from the western Great Lakes States. Banik *et al.* (1995) identified *A. sinapina* on several conifer and deciduous species in Wisconsin and Michigan, but not on *A. saccharum*. In both Ontario and New York, *A. sinapina* has been associated with cambial infection as well as butt rot (Blodgett and Worrall 1992, McLaughlin 2001a). More intensive sampling is required to suggest roles for either of these two *Armillaria* species in the Chequamegon forest.

The predominance of *A. ostoyae* in the Chequamegon is consistent with results of other collections of *Armillaria* from sites in the western Great Lakes States that are, or once were, dominated by conifers (Banik *et al.* 1995, Rizzo *et al.* 1995, Smith *et al.* 1994). In the Chequamegon, *A. ostoyae* was identified on five

Table 4.—*Previously published accounts of* Armillaria *species in the western Great Lakes States*

Reference	*Armillaria* spp.	Associated host or substrate	Vegetation on the site at the time / past (if known)	Location
Kromroy 1999	*A. ostoyae*	*Abies balsamea*	8-yr-old conifer plantation / mixed hardwoods	Rhinelander, WI
	A. ostoyae	*Quercus rubra, Populus deltoides*	30-40 yr-old *Pinus resinosa* plantation / *Quercus* spp.	Black River Falls, WI
	A. ostoyae	*Corylus cornuta, Vaccinium angustifolium, Populus* spp., *Amelanchier sanguinea*	*P. resinosa* plantations / upland forest of *P. resinosa, P. strobus,* & *P. banksiana, Picea-Abies* & *Populus-Betula*	Cloquet, MN
	A. sinapina	Debris in the soil	Same as above	Cloquet, MN
	A. gallica	Rhizomorphs in the soil	20-60-yr-old *P. resinosa* plantation / *Quercus* spp.	Black River Falls, WI
Banik *et al.* 1995	*A. calvescens*	*Acer saccharum, Betula papyrifera, Lonicera* spp., *Populus tremuloides, Quercus rubra, Q. velutina, Tilia americana, Ulmus* spp.	Not described	Upper Peninsula (UP), MI; central MN; southwestern WI
	A. gallica	*A. balsamea, P. resinosa, P. strobus, Acer rubrum, A. saccharinum, A. saccharum, B. papyrifera, Carya ovata, Fraxinus pennsylvanica, P. tremuloides, Prunus serotina, Quercus alba, Q. ellipsoidalis, Q. macrocarpa, Q. rubra, Q. velutina, Ulmus* spp., duff	Not described except for some collected in *P. tremuloides* stands	UP MI; eastern MN; WI
	A. mellea	*A. saccharum, Quercus* spp.	Not described	UP MI; SE MN; west-central & southern WI
	A. ostoyae	*A. balsamea, Picea glauca, P. banksiana, P. resinosa, P. strobus, Thuja occidentalis, Tsuga canadensis, A. rubrum, A. saccharum, Betula alleghaniensis, B. papyrifera, Fraxinus nigra, P. tremuloides, Q. rubra, Q. velutina, Ulmus* spp.	Not described except for some collected in *P. tremuloides* stands	UP, MI; central MN; NE & central WI
	A. sinapina	*A. balsamea, T. occidentalis, T. canadensis, A. rubrum, B. alleghaniensis, F. nigra, P. tremuloides, Q. rubra*	Not described except for some collected in *P. tremuloides* stands	UP, MI; northern WI

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(Table 4 continued)

Reference	*Armillaria* spp.	Associated host or substrate	Vegetation on the site at the time / past (if known)	Location
Rizzo *et al.* 1995	*A. ostoyae*	*P. banksiana*; hardwood regeneration; conifer & hardwood stumps	Clearcut; *P. banksiana* planted / *P. resinosa - P. banksiana*	Cloquet, MN
	A. ostoyae	*P. resinosa, P. banksiana, A. balsamea, A. rubrum, B. papyrifera*	*P. resinosa - P. banksiana* with mixed deciduous / estab. after 1894 fire	Cloquet, MN
Smith *et al.* 1994	*A. ostoyae*	*P. resinosa, A. rubrum, Populus* sp., *B. papyrifera* stumps	*P. resinosa* seedling plantation / northern hardwood forest	Northern MI
	A. sinapina	*Populus* sp. stump	Same as above	Northern MI
Smith *et al.* 1992	*A. bulbosa* = *A. gallica*	Fruiting bodies & rhizomorphs in soil	Northern hardwood forest	Northern MI
Smith *et al.* 1990	*A. ostoyae* & *A. bulbosa* = *A. gallica*	Fruiting bodies	*P. resinosa* seedling plantation / northern hardwood forest	Northern MI
Proffer *et al.* 1987	*A. ostoyae*	*Prunus cerasus, P. avium, P. persica, Malus pumila*	*Prunus* orchards	Lower Peninsula, MI
	NABS[1] III = *A. calvescens*	*P. cerasus*	*Prunus* orchards	Lower Peninsula, MI
	A. mellea	*P. cerasus , Quercus* sp. stumps	*Prunus* orchards	Lower Peninsula, MI
Stanosz & Patton 1987	*A. mellea* sensu lato[2] (no isolation)	*Populus* spp; suckers & stump	Short rotation *Populus* plots / mature *Populus* stand	Grand Rapids, MN
Livingston *et al.* 1982	*A. mellea* sensu lato	*A. balsamea*	*A. balsamea* plantation / 50-60-yr-old hardwood stand	Grand Rapids, MN
Pronos & Patton 1978	*A. mellea* sensu lato	*Q. alba, Q. rubra*	Natural *Quercus* stands, sprout origin, herbicide treated and untreated	Black River State Forest, WI
Pronos & Patton 1977	*A. mellea* sensu lato (no isolation)	*P. resinosa*	*P. resinosa* plantation, *Quercus* overstory, herbicide treated / natural *Quercus* stands, sprout origin	Northwest, northeast, & west-central WI

[1] North American Biological Species, an intersterile population identified within the original *A. mellea* complex.
[2] Refers to the original *A. mellea* complex before its separation into several species.

conifers—*Abies balsamea* (L.) Mill., *Picea glauca* (Moench) Voss, *Pinus banksiana* Lamb., *P. resinosa* Ait., and *P. strobus* L. and three deciduous species—*A. saccharum*, *Populus tremuloides* Michx., and *Betula papyrifera* Marsh (table 5). All have been previously reported as hosts of *A. ostoyae* in this region.

Although its pathogenicity toward deciduous species is less clear (Gregory *et al.* 1991), *A. ostoyae* is a serious pathogen of several conifer species (Blenis 2000, Cochran 1998, Rosso and Hansen 1998, Whitney 1995). It invades the roots of trees already stressed, but may also penetrate the bark and kill the cambium in the roots and root collar of healthy trees, resulting in their death (Gregory *et al.* 1991, Kile *et al.* 1991). Root disease from *Armillaria* species is a contributing factor in several declines. "Decline" is a disease syndrome caused by interactions among predisposing (e.g., site quality, tree age), inciting (e.g., drought, insect defoliation) and contributing (e.g., two-lined chestnut borer) factors (Manion 1991). Some species in this genus, such as *A. ostoyae*, may also act as a predisposing factor by requiring a small but constant drain of host resources to defend against chronic low-level infections that occur on otherwise healthy roots (J. McLaughlin, personal communication). By also deriving nourishment saprophytically from stumps and debris, *A. ostoyae* can survive on a site for many years.

Table 5.—Armillaria ostoyae[1] *and host associations from the Chequamegon area of the Chequamegon-Nicolet National Forest*

Host species	Host condition	D.b.h.[2] (cm)	Stand[3]
Acer saccharum	Dead	10	G4A
Betula papyrifera	Dead, in clump with live	15	W2
Populus tremuloides	Dead	<1	G3
Abies balsamea	Dead	<1	G3
		31	H2
		32	H5
	Stump, broken	30	PF2
Picea glauca	Dead	38	G5
		NR[4]	H1
	Stump, cut	NR	H1
		26	H3
		15	H3
Pinus banksiana	Live, declining	20	PF1
	Dead	13	PF5A
		28	W1
	Snag	20	PF5A
Pinus resinosa	Live, suppressed	15	H7
	Dead	10	G3
	Stump, cut	60	G2
		38	H7
Pinus strobus	Dead	44	G1

[1] A single isolate of *A. calvescens* was collected from a dead stem of *A. saccharum*, 4 cm d.b.h., growing in a clump of live and dead, site PF4. A single isolate of *A. sinapina* was collected from a single dead *A. saccharum*, 13 cm d.b.h., site G4B.

[2] D.b.h.: Diameter at 1.4 m above ground for stems, at ground level for stumps.

[3] Refers to the ranger district and stand number as shown in figure 1.

[4] Not recorded.

The most notable mortality observed in this study was of the jack pine in stand 5A in the Park Falls district and the white spruce in stand 1 in the Hayward district. Although the exact role of *Armillaria* root disease in these stands was not clear, it probably contributed to the situation. Other factors in the jack pine mortality appeared to be the maturity of the trees, the exposure of the site, and the presence of bark beetles and other root and butt rot fungi. Factors in addition to *Armillaria* root disease that may have been contributing to the white spruce mortality were heart rot associated with *Phellinus pini*, premature needle loss and branch mortality associated with *Rhizosphaera kalkhoffii* (Juzwik 1993), drought stress, and poor soils (USDA 1990).

Between the 1983 and 1996 cyclic inventories, the USDA Forest Service, Forest Inventory and Analysis (FIA) unit reported that the total area of deciduous forest types in the Chequamegon increased by 23 percent while the total area of conifer forest types decreased by 18 percent, due largely to reductions in jack pine and white spruce forest types and reduced growing-stock volume for both these species (Haugen *et al.* 1998). Changes in harvest practices, natural forest succession, and weather patterns contributed to these changes, but most likely so did insect outbreaks and diseases, including *Armillaria* root disease. Evidence of the significance of *A. ostoyae* in forest succession and composition has been reported by McLaughlin (2001b) in areas of southern Ontario. Hardwood species are colonizing openings where *A. ostoyae* has killed the red pine. Although some mortality is occurring among the hardwoods, in general they appear less susceptible than the red pine and are expected to eventually dominate these sites.

CONCLUSIONS

The occurrence of *A. ostoyae* on eight overstory species, coniferous and deciduous, and its presence in most of the stands that were examined are consistent with other reports documenting the broad host range and widespread distribution of *A. ostoyae*, both in the western Great Lakes States and in other areas of North America. Although additional data are required to draw more definitive conclusions, based on the findings of this study, *A. ostoyae* should be viewed as an integral component of the Chequamegon forest landscape, capable of causing root disease and thus a likely contributor to decline and mortality of overstory species, especially conifers.

ACKNOWLEDGEMENTS

Partial funding for this study came from the USDA Forest Service, Forest Health Protection Unit. I thank Joseph O'Brien for his assistance in identifying sites and collecting sample material, and Paul Castillo for his help in preparing the manuscript. I am grateful for the help and insight provided by my three manuscript reviewers—Joseph O'Brien, Plant Pathologist, USDA Forest Service, State and Private Forestry; Mike Ostry, Research Plant Pathologist, USDA Forest Service, North Central Research Station; and John McLaughlin, Forest Research Pathologist, Ontario Forest Research Institute.

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